1.0 INTRODUCTION

1.1 General Problem Statement

Pavement evaluation in pavement management systems (PMS) is generally directed toward the following objectives *(Haas et al. 1994)*:

1. Selection of projects and treatment strategies at the network level, and
2. Identification of specific maintenance requirements at the project level.

Each of these objectives requires pavement evaluation information to greater or lesser degrees of detail. In the case of lesser detail, aggregation of the individual measures comprising the information, such as a composite or combined measure of pavement quality, is widely used. Such a combined measure for each pavement section is helpful at the network level for technical decisions, e. g., project selection.

At the network level, Nondestructive Testing (NDT) can be used to identify the beginning and end of management sections and group pavement sections with similar structural capacities for condition prediction, and to identify pavement projects for project-level testing and evaluation *(Shahin 1994)*. Without NDT testing, there is a risk of defining pavement management sections that may appear uniform based on observed distress alone, but in reality they are not. In Kansas, one type of pavement management section is known as a "control section." A control section is "a segment of roadway with reasonably uniform geometric, traffic, surface, and base characteristics for its entire length." These sections are used for project prioritization purposes by the Kansas Department of Transportation (KDOT).

Due to limited resources and large size of the network (17,660 km or 10,971 miles), network-level structural data collection annually by KDOT at the same intervals (5 to 10 tests per mile) as the project level is not realistic. Although guidelines exist for test intervals at the project level *(Karan et al. 1981; Koole 1979; Way et al. 1981; Mamlouk et al. 1990; Hossain and Zaniewski 1992; Shahin 1994),* not many studies have been conducted to determine the test intervals at the network level. Lytton et al. *(1990)* evaluated the minimum number of Falling Weight Deflectometer (FWD) tests required to provide accurate representation of the structural capacity of the pavement section at the network level. They concluded that a minimum of five tests per mile are required to provide a ranking of a pavement section which is highly correlated to the actual ranking. The actual ranking is the one that would be obtained by doing as many tests as possible. KDOT owns two Dynatest 8000 FWD. Currently, each unit is capable of testing up to 20 lane-miles in a 10-hour day during a deflection survey period which runs from April thru October. With this production level, to test the entire network (17,660 lane km or 10,971 lane miles) annually, 275 days of testing would be necessary just at the network level! This does not include the time spent in travel from one project to the other. Thus, one of the objectives of this study was to determine the test sample size (percent mileage) at the network level as well as the test intervals and frequency.

In the Priority Ranking Procedure of KDOT, a composite measure of pavement quality, Pavement Structural Evaluation (PSE), is used. The rating for pavements is on a scale of 0 to 10, 10 being the best or no work required. In the ranking procedure, PSE is expected to be an indicator of the control section structural deficiency *(Clark 1989)*. The attributes and relative weights used in the prioritization process for the interstate highways are as follows:

Attribute	**Relative Weight**
Commercial Traffic Index	0.140
Rideability	0.189
PSE	0.447
Observed condition	0.224

Thus the relative weight of the PSE attribute in the interstate roadway priority formula is twice the next weighted attribute of observed condition. The same importance is attached to the PSE rating attribute for non-interstate roadways *(Comstock 1992)*.

PSE ratings are furnished by the district offices of KDOT and are based on the condition and strength of base and surface, as indicated by maintenance costs, subgrade failures, and ability of the section to provide an adequate surface for the type of expected traffic *(Chowdhury 1998)*. Table 1.1 shows the rating guide used by the KDOT districts for the bituminous pavements. Since the implementation of a network-level PMS (known as Network Optimization System or NOS) by KDOT in the late eighties, PSE is the only input the Districts have into the project prioritization process.

The Geotechnical unit provides a possible range of PSE values for each control section based on algorithms developed by the experts in that unit using the PMS data. However, these values did not appear to be helpful to the districts and in some cases, led to confusion. Since KDOT does not collect any deflection data at the network level, the PSE computation process does not take into account any structural evaluation. However, some of the distresses considered are structure-related. Engineering judgment indicates that a better measure of structural evaluation can be developed using results from the in-situ deflection tests, such as Falling Weight Deflectometer (FWD) tests and network-level distress survey.

Table 1.1 PSE Rating Guide for Bituminous Surfaces

PSE Value	Pavement Condition
10	Nearly new condition. No maintenance or distress expected for three or more years. When a recent action produces a current condition that is expected to last less than three years, consider making the rating in light of the condition before recent action.
8~9	Slight (<1/4") rutting in at least 1 wheelpath; and/or fine alligator cracks; little or no surface maintenance needed.
6~7	Moderate (½") rutting continuous in 2 or more wheel paths; and/or secondary transverse cracks or moderate (1/4") transverse cracks with little or no roughness associated with crack; and/or alligator cracks associated with ruts; and/or minor shoving, spot edge failures, or hairline block cracks; requires spot patching and major patching.
4~5	Significant (>½") rutting in wheel paths; and/or wide (>½") transverse cracks with roughness developing at cracks and/or shoving may be present; and/or alligator cracks associated with deep ruts, or vertical displacement; and/or edge failures, and/or spalling associated with block cracks; requires frequent patching and major patching.
2~3	Very wide (>3/4") or depressed transverse cracks resulting in unacceptable surface roughness; and/or continual edge failures or shoving along pavement edge at transverse cracks; and/or block cracking that is <4" in any dimension with spalling associated with the cracks; requires major patching; high potential for winter or spring breakup.
0~1	Continual patching and major patching required; or milling required to remove ruts and/or roughness due to depressed transverse cracks; beyond economical maintenance by KDOT forces.

1.2 Objective of the Study

The primary objective of this study was to investigate the potential of FWD deflection data to augment the Pavement Structural Evaluation (PSE) value computation. Another objective was to determine the FWD test sample size (percent mileage) at the network level, and test intervals and frequency needed to provide input into the network-level structural evaluation and PSE computation process.

1.3 Approach of the Study

The following variables, which directly or indirectly influence the pavement structural condition, were investigated as potential predictors of the PSE values:

1. Age of the pavement (in years) *since the last rehabilitation action*,
2. Cumulative 18 kip Equivalent Single Axle Loads (ESAL's) that have passed over the section *since the last action*,
3. Asphalt Concrete (AC) layer thickness,
4. Structural number (SN) of the pavement, and
5. Distress level due to transverse cracking.

It is to be noted that pure deflection values were not used as predictors. Rather the structural number of the pavement which can be derived from the deflection results is used as a predictor. This was done because a pavement with a strong subgrade and weak AC, base and subbase layers may have the same first sensor deflection value as a pavement with a weak subgrade and strong AC, base and subbase layers. The structural number, on the other hand, is known to be more representative of the structural condition of the layers above subgrade. However, since the deflection results are mostly unaffected by transverse cracking (FWD tests are conducted away from the cracks), the distress level of transverse cracking was used as a predictor. Multiple linear regression models were developed with the above predictors as independent variables to objectively quantify the decrease in the PSE values.

A parallel study by the junior author for his master's thesis *(Chowdhury 1998)* used the Bayesian regression modeling approach to objectively quantify the decrease in the PSE values. XLBAYES, an EXCEL-based software, was used to develop similar models using the same variables used in the multiple linear regression analysis done earlier. Bayesian regression modeling has been introduced by the Canadian Strategic Highway Research Program (C-SHRP) for analyzing the Canadian Long-Term Pavement Performance (C-LTPP) data. Chowdhury *(1998)* also tested the models developed by the classical regression and Bayesian regression on a different set of data, and appropriate models were recommended for global use on the KDOT network.

1.4 Synopsis

This report is divided into seven chapters. In Chapter 1, the introduction to the problem, the objectives of this study, and study approach are discussed. In Chapter 2, a literature review of previous work is presented. Chapter 3 deals with the determination of FWD test sample size (percent mileage), and test intervals, and frequency at the network level. It also discusses the network-level pavement structural evaluation. Regression models were developed to predict the decrease in the structural number, and thus, forecasts were made on the structural deterioration of the pavements in Kansas. In Chapter 4, multiple linear regression analysis was performed to predict the decrease in PSE values by using variables which reflect the structural, climatic, traffic and surface condition of the pavements. Chapters 5 and 6 have been borrowed from the master's thesis of Chowdhury *(1998)*. Chapter 5 describes the Bayesian Regression and its application in the determination of PSE values using the same set of variables as in the classical regression analysis. Chapter 6 analyzes the performance of the selected models on a different set of pavements with data from different years. The performances of the classical and Bayesian models are also compared. Finally, Chapter 7 presents the conclusions and recommendations.